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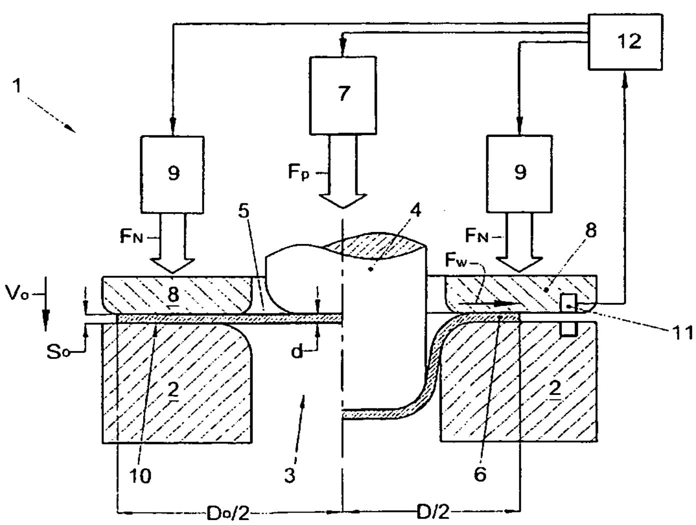
(54) Title: METHOD AND APPARATUS FOR REDUCING WRINKLE FORMATION IN DEEP DRAWING



(57) **Abstract:** A method and apparatus for deep drawing a product from a blank(5), in which, during deep drawing, the blank(5) is held near its edge by a downholder (8) against a die ring cooperating with the downholder (8), thereby preventing, at least reducing wrinkle formation in the blank, by adjusting, at the beginning of deep drawing, the downholder (8) such that a downholder (8) force exerted by the downholder (8) on the edge of the blank is relatively small, and by controlling, during the further course of the process, the downholder (8) on the basis of a predetermined thickness trend of the mentioned edge during deep drawing and/or a trend or critical value derived from this thickness trend.

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Title: Method and apparatus for reducing wrinkle formation in deep drawing

The invention relates to a method for deep drawing products from a blank. More in particular, the invention relates to an improved method for preventing, at least reducing wrinkle formation in the blank during deep drawing.

During deep drawing a blank between a die and a punch cooperating therewith, the edges of the blank are held by means of a downholder against a die ring cooperating with this downholder. It is important here to adjust the downholder such that a downholder force exerted on the edges of the blank is, on the one hand, sufficiently great to prevent wrinkle formation in the edges, but is, on the other hand, not greater than is necessary, because this promotes crack formation and, moreover, leads to high frictional forces between the blank and the downholder and die ring. Such frictional forces require a heavy design of the apparatus, cost unnecessarily much energy during deep drawing, lead to wear, and shorten the life of the apparatus.

In the known methods, the required downholder force is often determined by 'trial and error' during a series of experiments preceding the actual deep drawing process. The found downholder force is then multiplied by a security factor, in connection with possible variations in the starting material, such as spreading in thickness and composition. As a result thereof, the used downholder force is eventually higher than is absolutely necessary, with all the above-mentioned attendant drawbacks. Moreover, the experiments cost time, material, and money, and the outcome is dependent on the expertise of those who carry out the experiments.

DE 4 038 864 discloses a method in which at the beginning of deep drawing the downholder force (F_N) is preventively chosen so high that this force is greater than a counterforce (F_s) to be expected in the blank. During

deep drawing, the downholder force is gradually reduced until a beginning of wrinkle formation is observed. Then the downholder force is increased to above the counterforce expected in the blank at that moment. This is repeated until, at the end of the deep drawing process, the downholder force is equal to zero. The wrinkle formation is detected by means of measuring means which measure the distance between the downholder and the die. The reproducibility of this publication lacks because it is not explained in a manner clear to those skilled in the art how to determine the counterforce to be expected. Moreover, it is remarkable that in the known proposal the exerted downholder force decreases while, as will turn out below, in the proposal according to the invention the downholder force exactly increases in the course of the process.

In this known method, too, the downholder force is therefore higher than is necessary because, at the beginning of the method and each time when wrinkle formation occurs, this force is increased to above the counterforce to be expected in the blank. Moreover, the height of the downholder force and the good action thereof is strongly dependent on the accuracy with which the counterforce can be predicted.

The invention contemplates providing a method in which at least a number of the drawbacks inherent to the known methods are removed. To this end, a method according to the invention is characterized by the measures according to claim 1.

In a method according to the invention, the downholder force is initially kept relatively low and increased only when this is necessary, that is to say at a beginning wrinkle formation. It is important here that this wrinkle formation can be recognized at an early stage. In a method according to the invention, this is achieved by taking into account the thickness trend of the edge of the blank during deep drawing or a magnitude derived from this thickness trend, such as, for instance, the speed of the thickness trend. The thickness of the blank edge gradually

increases during deep drawing, because the diameter of the blank gradually decreases and, therefore, material in the blank edge must be accommodated on an increasingly smaller surface. If this thickness increase were not taken into account, then every thickness increase would be considered a beginning wrinkle formation, and the downholder would wrongly be controlled, during which not only wrinkles, but also the mentioned thickness increase would be suppressed, which leads to an unnecessarily high downholder force.

In a method according to the invention, during deep drawing the downholder force is gradually increased from a relatively low value, instead of decreased from a preventively high value. As a result thereof, the downholder force will always have a lowest possible value, resulting in low frictional forces between the apparatus and the blank. Consequently, the apparatus can be operated at relatively low forces and relatively little energy and thus be of relatively light design. Moreover, at such low forces the risk of cracks of the blank will be minimal. As a result thereof, less stringent requirements can be imposed on the starting material with respect to, for instance, the homogeneity of the material, the number of imperfections in the material grid per volume unit and thickness variations in the blank. In this manner, with qualitatively inferior starting material and at correspondingly lower material cost a qualitatively good final product can yet be realized. Moreover, the freedom in materials to be used thus increases, so that new materials can more easily be used.

Another advantage over the known methods is that a counterforce to be expected in the blank need not be determined previous to deep drawing. Nor need time-consuming and expensive tests be carried out to determine a suitable beginning downholder force, which is of great advantage, particularly for relatively small product series.

Tests of applicant have shown that if during deep drawing wrinkle formation in the edge of the blank is prevented in the above-described manner, both wrinkles in the flange of the deep-drawn final product (so-

called primary wrinkles) and wrinkles in the wall of the deep-drawn final product (so-called secondary wrinkles) can be effectively prevented. In this specification, the 'edge of the blank' is understood to mean the part of the blank located between the downholder and the die ring.

In a first preferred embodiment, a method according to the invention is characterized by the measures according to claim 2.

In this embodiment, a parameter relevant to wrinkle formation is measured and the downholder force is increased if this measured parameter exceeds a predetermined critical range or critical value, which range or which value is based on, at least takes into account, the above-discussed thickness increase of the blank or a magnitude derived from this thickness increase.

The downholder force can be increased stepwise, by a predetermined step size, but can, for instance, also be regulated to a desired value by means of known per se regulating algorithms, such as, for instance, a proportionally, integratingly and/or differentiatingly operating regulation, the measured parameter again being located below the mentioned critical magnitudes (range or value).

In a further elaboration of the first preferred embodiment, a method according to the invention is characterized by the measures according to claim 3.

The parameter relevant to wrinkle formation may, for instance, be the downholder opening, defined as the perpendicular distance between the downholder and the die ring. In that case, the thickness trend or the maximum thickness increase of the blank edge can be entered as critical range or critical value, respectively. For if during deep drawing the downholder opening becomes larger than the momentary thickness or the eventual maximum thickness of the blank edge, this indicates wrinkle formation. The thickness trend can be theoretically determined, by means of suitable simulation programs, but can also be measured once, previous to

deep drawing of a new series of products. To this end, a constant downholder force is adjusted, at which neither wrinkle formation, nor crack formation occurs, and the downholder opening is measured during deep drawing. Since no wrinkle formation occurs, it may be assumed that the measured downholder opening is substantially equal to the thickness increase of the blank. It is assumed here that the measured thickness increase is independent of the adjusted downholder force, or at least that the influence of the height of the downholder force on the measured thickness increase is negligibly small, within the operative area of the downholder force important to the present use.

In a further elaboration of the first preferred embodiment, a method according to the invention is characterized by the measures according to claim 4.

Instead of or besides the downholder opening, the speed at which this opening changes may also function as critical magnitude. This speed may also be determined by simulation or a testing measurement, in the above-described manner. Then the speed trend may function as critical range or a speed value measured to be highest during this trend as critical value. The downholder opening speed trend is more sensitive than the downholder opening trend, so that wrinkle formation can be recognized at an even earlier stage.

Of course, both signals, the downholder opening trend and the downholder opening speed trend, may also be used side by side, the critical value or the critical range that is exceeded first being decisive of the control of the downholder.

In a second preferred embodiment, a method according to the invention is characterized by the measures according to claim 7.

In this method, not the downholder force, but the downholder position is regulated, based on a predetermined thickness trend of the blank. This thickness trend may, in the same manner as discussed before, be simulated

or measured. On the basis of this thickness trend, the downholder may always be adjusted during deep drawing such that the downholder opening is substantially equal to the predetermined momentary thickness of the blank. Such a method according to the invention offers the advantage that during deep drawing the downholder opening and downholder speed need not be measured and compared with a predetermined critical value. Moreover, in this embodiment, too, the downholder force will be minimal, at least not greater than necessary, with all the attendant above-mentioned advantages.

Of course, a combination form of both preferred embodiments according to the invention is possible as well, with primarily the position of the downholder being regulated on the basis of a predetermined thickness trend of the blank and secondarily the downholder opening trend and/or downholder opening speed trend being measured so that when the predetermined thickness trend does not fully correspond with the real thickness trend (for instance, because of variations in the starting material or hysteresis in the downholder movement) correcting action can be taken by increasing the downholder force.

The invention further relates to an apparatus for deep drawing a product from a blank, suitable for use of a method according to the invention.

In the further subclaims, further advantageous embodiments of a method and apparatus according to the invention are described.

In explanation of the invention, an exemplary embodiment of a deep drawing apparatus and a method according to the invention will be elucidated in more detail with reference to the drawing. In this drawing:

Fig. 1 schematically shows a deep drawing apparatus according to the invention;

Fig. 2 shows a diagram in which the trends of the upper and lower limits of the admissible downholder force are plotted as a function of the deep drawing ratio;

Fig. 3 shows a testing measurement with a downholder force for determining a critical value and/or range in which wrinkle formation occurs;

Fig. 4 a measurement in which the downholder opening and the downholder force are plotted against time, with and without regulation according to the invention;

Fig. 5A shows a simulation of the speed trend of the downholder opening (v_o) during deep drawing;

Fig. 5B shows a simulation of the downholder force (F_N), regulated on the basis of the speed from Fig. 5A;

Fig. 6 shows a photograph of a deep drawn product, with and without regulation according to the invention;

Fig. 7 shows a deep drawn product with primary and secondary wrinkles.

Fig. 1 shows an apparatus 1 for deep drawing products, with which wrinkle formation in those products can be reduced and preferably be completely suppressed. In this specification, wrinkle formation is understood to mean the formation of both primary wrinkles 21 in a flange 6 of the deep drawn product 15 and secondary wrinkles 22 in wall parts 25 of the product 15, as illustrated in Fig. 7. The apparatus and method according to the invention are directed to suppressing both types of wrinkles.

The apparatus 1 comprises a die 2 provided with a die opening 3 and a punch 4 arranged above this die opening 3. This punch 4 can be moved by means of suitable positioning means 7 into the opening 3, as shown in Fig. 1 on the right side. A blank 5 of starting material placed over the opening 3 is thereby forced into the opening 3 and deformed between the walls of this opening 3 and the punch 4 to a desired final product 15. As appears from a comparison of the left and the right half of Fig. 1, the starting diameter D_o

of the blank 5 gradually decreases during this deep drawing, which is accompanied by an increase in the thickness d of the edge 6 and can further lead to wrinkle formation.

In order to prevent the edge 6 from wrinkling and rising during deep drawing, a ring-shaped downholder 8 is arranged around the punch 4, which downholder can be moved with suitable positioning means 9 towards a die ring 10 extending around the die opening 3 while clamping the edge 6 of the blank 5. A downholder force F_N exerted on the edge 6 by the downholder 8 will thereby increase according as the downholder opening s_o, defined as the perpendicular distance between the downholder 8 and the die ring 10, increases.

During deep drawing, the downholder force F_N must remain between two extreme limits, a lower limit $F_{N,min}$ and an upper limit $F_{N,max}$. These limits are graphically shown in Fig. 2, as a function of the deep drawing ratio. When the downholder force F_N falls below the minimum limit $F_{N,min}$, wrinkles will be formed in the product, while at exceeding the maximum limit $F_{N,max}$ cracks will be formed in the product 15. In practice, the downholder force F_N is therefore adjusted to a 'safe' distance between both limits, so that a certain safety margin is present, in connection with possible spreading in the starting material (composition, thickness, etc.).

In a method according to the invention, the downholder force F_N is contrarily exactly kept as close to the lower limit $F_{N,min}$ as possible. The risk of crack formation will thus be reduced to a minimum. Moreover, this will also limit frictional forces F_w occurring during deep drawing between the blank 5 and the downholder 8 and the die ring 10, since these frictional forces are proportional to the downholder force F_N. Lower frictional forces ensure that less lubricant suffices, that the deep drawing process can take place under lower forces, with less work, and that the whole arrangement can be of lighter design.

In order to keep the downholder force F_N as low as possible, at the beginning of deep drawing it is adjusted according to the invention to a low value and increased only if wrinkle formation occurs. Then the downholder force is increased to a value necessary to suppress the detected wrinkles. The downholder force F_N will thus always be not greater than necessary to suppress the momentary wrinkle formation.

For this method to function well, it is important to be able to detect wrinkle formation at an early stage. It has been found that both the downholder opening trend s_o and the derivative thereof over time, the downholder opening speed trend v_o, are measuring signals usable therefor. For these signals s_o and v_o, a critical value can be determined in a manner to be described below in more detail, exceeding of which involves wrinkle formation.

The deep drawing apparatus 1 of Fig. 1 is therefore provided with measuring means 11, with which the mentioned downholder opening trend s_o and/or downholder opening speed trend v_o can be measured. These measuring means 11 may, for instance, comprise an optical, capacitive or magnetic sensor. The measuring means 11 are connected to a control 12, which is provided with means for comparing the measuring signals with a critical value or critical range adjusted for those signals, and which control 12 is further arranged to move, in case of exceeding the mentioned critical magnitudes, the downholder 8 towards the die 2 by means of the positioning means 9. These positioning means 9 may, for instance, comprise a piston-cylinder assembly, an electrically driven screw spindle, a piezo-electric element, or the like.

Previous to deep drawing a new product series, the critical values can be determined during a testing measurement, by measuring, during this test, the downholder opening trend s_o as shown in Fig. 3. It is clearly visible that the downholder opening s_o initially has a substantially constant value (range I-II) and then gradually increases at a constant inclination (range

II-III) corresponding with a constant downholder opening speed v_o. From point III, the measured downholder opening trend s_o shows a bend, and this trend increases more rapidly, which indicates wrinkle formation P. On the basis of this measurement, therefore, the range I-III can be implemented in the control 12 as the sought critical downholder opening range. Instead thereof, bend point III may also be introduced as critical downholder opening value. When a downholder opening trend s_o measured during deep drawing exceeds the critical range or the critical value, the thickness increase is greater than may be expected on the basis of the testing measurement, which indicates wrinkle formation.

In a slightly modified variant of the above-described method for determining the critical values, the deep drawing testing measurement may also be carried out at such a high downholder force F_N that neither wrinkle formation, nor crack formation will occur. This allows for the assumption that a downholder opening trend s_o measured during this test fully corresponds with the thickness increase of the edge 6 of the blank 5. This measured downholder opening trend may therefore be implemented in the control 12 as critical range. Instead thereof, the maximally measured thickness increase may also be introduced as critical value.

In a comparable manner, besides or instead of the downholder opening, the speed v_o at which this downholder opening changes may also be measured during the mentioned testing measurement. This measured speed trend or a speed value measured to be highest during this measurement can be introduced into the control 12 as critical range or critical value for the downholder opening speed trend.

When a downholder opening speed v_o measured during deep drawing exceeds this critical range or this critical value, this indicates wrinkle formation, since the downholder opening increases more rapidly than may be expected on the basis of the normal thickness increase.

Besides, it is pointed out that the critical speed value can also be determined by the inclination of range II-III in Fig. 3.

Fig. 4 shows a measurement of the downholder opening s_o and the downholder force F_N over time, with the thinly drawn lines representing the trend without regulation according to the invention, while the thickly drawn lines represent the trend when the downholder force F_N is controlled on the basis of the critical downholder opening determined in Fig. 3. It is clearly visible that the downholder force F_N is stepwise increased from the critical value determined in Fig. 3 (bend point III) and thus effectively suppresses (see thickly drawn s_o line) wrinkle formation (see thinly drawn s_o line).

Fig. 4 further clearly shows that the downholder force initially begins relatively low and is increased only if this is actually necessary. The force may be increased stepwise, at a predetermined step size, or may be increased proportionally to the measured deviation. Also possible are other known per se regulation techniques, in which, for instance, use is made of integrating and/or differentiating actions. The apparatus may also be provided with a self-learning regulation, in which the step size of the force F_N is initially adjusted by an operator, and the regulation itself adapts this value in the course of the process, on the basis of fed back measuring data.

In Fig. 5A,B is shown a simulation in which the downholder force is regulated on the basis of the measured opening speed v_o and a critical speed value predetermined in the above-described manner, which, in the shown case, was approximately 1×10^{-4}. It is clearly visible how the downholder force F_N is increased stepwise, each time when the downholder opening speed exceeds the critical value. It is also visible that the increase of the downholder force F_N is greater according as the exceeding of the critical value is greater.

Fig. 6 shows, on the left side, a flange 6' of a product 15', manufactured with a conventional deep drawing method (see the thinly drawn lines in Fig. 4), while next to this, on the right side, a product 15 is

shown, which has been manufactured with a method according to the invention (see the thickly drawn lines in Fig. 4). It clearly appears that the product according to the present method substantially has no wrinkles.

It will be clear that the critical values for the downholder opening and the opening speed depend on the starting material and the desired final product. These values are therefore determined again, preferably preceding each new product series. This may be done by means of a testing measurement, as described above. In case of sufficient material data and process data, these values may also be simulated by means of known per se software packages, so that no testing measurements at all need be carried out anymore.

In an alternative embodiment of a method according to the invention, not the downholder force is regulated on the basis of a measured beginning of wrinkle formation (feed-back regulation), but the position of the downholder and hence the downholder opening are regulated according to a predetermined range, such that the mentioned downholder opening corresponds with the thickness trend of the blank 5 to be expected (forward regulation). The thickness trend to be expected may be determined in the same manner as described before with reference to Fig. 3. Such a forward regulation has the advantage that during the actual deep drawing no downholder opening or speed need be measured, so that a very simple apparatus, without measuring means and without advanced control, suffices.

The invention is by no means limited to the exemplary embodiments shown in the specification and the drawing. Many variations thereof are possible within the scope of the invention defined by the claims.

Thus, depending on, inter alia, the distance over which deep drawing is effected and the thickness of the starting blank, deep drawing may take place in one or more steps. Furthermore, the forward position regulation

and fed-back force regulation may be combined, the force regulation being able to correctingly act on the position regulation.

These and many variations are considered to fall within the scope of the invention defined by the claims.

CLAIMS

1. A method for deep drawing a product from a blank, in which, during deep drawing, the blank is held near its edge by a downholder against a die ring cooperating with the downholder, thereby preventing, at least reducing wrinkle formation in the blank, by controlling the downholder, characterized in that at the beginning of deep drawing the downholder (8) is adjusted such that a downholder force (F_N) exerted by the downholder (8) on the edge (6) of the blank (5) is relatively small and the further control of the downholder (3) occurs on the basis of a predetermined thickness trend of said edge (6) during deep drawing and/or a trend or critical value derived from this thickness trend.

2. A method according to claim 1, characterized in that during deep drawing a parameter relevant to the wrinkle formation is measured and compared with a critical value at which wrinkle formation occurs, which critical value is predetermined, based on the thickness trend of the blank edge (6) and/or a signal derived from this thickness trend, and in which, when the measured parameter exceeds or threatens to exceed this critical value, the downholder (8) is controlled such that a downholder force (F_N) exerted on the edge (6) by the downholder (8) increases and the measured parameter falls below the critical value.

3. A method according to claim 2, characterized in that the parameter relevant to wrinkle formation is the downholder opening (s_o), defined as the perpendicular distance between the downholder (8) and the die ring (10), and the critical value is the predetermined thickness trend or the predetermined maximum thickness increase of the edge (6).

4. A method according to claim 2, characterized in that the parameter relevant to wrinkle formation is the speed (v_o) at which the downholder opening changes, and the critical value is the predetermined speed trend or

the predetermined maximum speed at which the blank edge increases in thickness during deep drawing.

5. A method according to any one of claims 2-4, characterized in that the critical value is measured during a testing session, previous to deep drawing.

6. A method according to any one of claims 2-4, characterized in that the critical value is simulated by means of a dynamic model of the blank (5) and the deep drawing process.

7. A method according to claim 1, in which the position of the downholder (8) is controlled according to a predetermined range, such that during deep drawing the downholder opening (s_o), defined as the perpendicular distance between the downholder (8) and the die ring (10) substantially corresponds with a predetermined thickness trend of the edge (6) to be expected during deep drawing.

8. An apparatus for deep drawing a product from a blank (5), comprising a downholder (8), a die ring (10) cooperating therewith, for holding an edge (6) of the blank (5) during deep drawing, a control (12) provided with means for storing therein a desired downholder opening trend (s_o), downholder opening speed trend (v_o) and/or a critical value derived therefrom, and positioning means (9) for moving the downholder (8), the control (12) being arranged to control the positioning means (9) such that the movement of the downholder (8) is in agreement with the stored downholder opening trend (s_o), downholder opening speed trend (v_o) and/or a critical value derived therefrom.

9. An apparatus according to claim 8, in which the control (12) is arranged to control the positioning means (9) such that a distance between the downholder (8) and the die ring (10) is in agreement with the stored downholder opening trend (s_o) or a critical value derived therefrom.

10. An apparatus according to claim 8 or 9, in which measuring means (11) are provided to measure the downholder opening trend (s_o), the

downholder opening speed trend (v_o) and/or a critical value derived therefrom, and in which the control (12) comprises means for comparing signals measured with the measuring means (11) with a downholder opening trend (s_o), downholder opening speed trend (v_o), stored in the control (12) and/or a critical value derived therefrom, and in which the control (12) is arranged to control, on the basis thereof, the downholder (8) such that the movement, speed or critical value of the downholder (8) derived therefrom is in agreement with the stored downholder opening trend, downholder opening speed trend and/or the critical value derived therefrom.

11. A apparatus according to any one of claims 8-10, characterized in that the measuring means (11) comprise a contactless sensor, for instance an optical, capacitive or magnetic sensor.

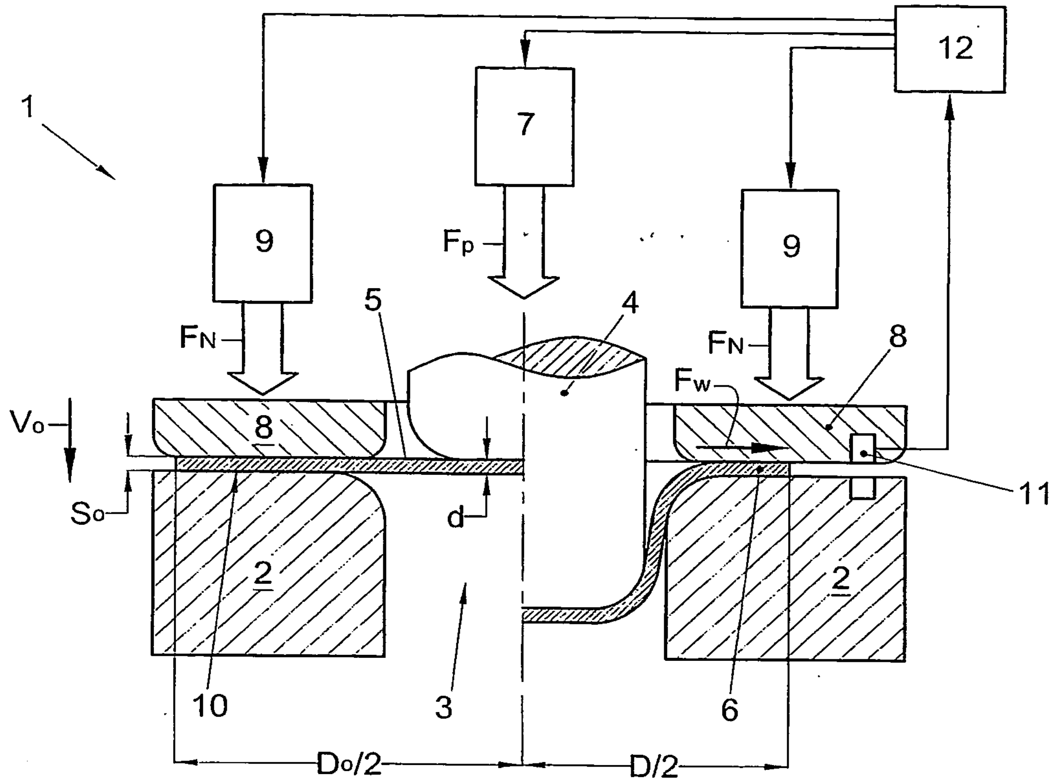
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Fig. 1

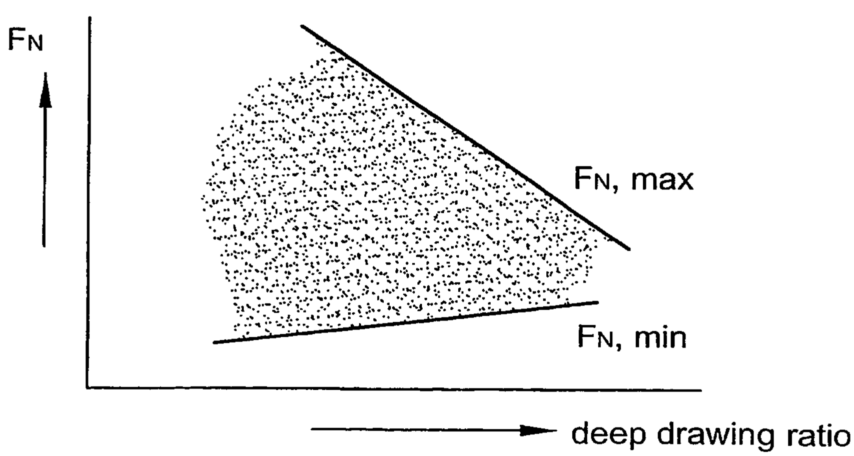
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Fig. 2

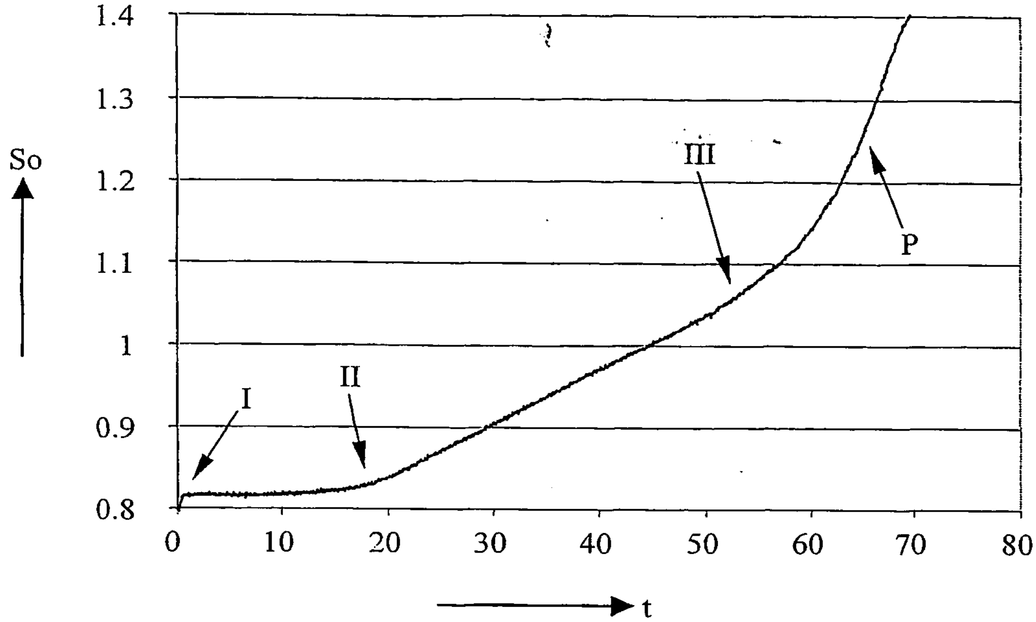
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Fig. 3

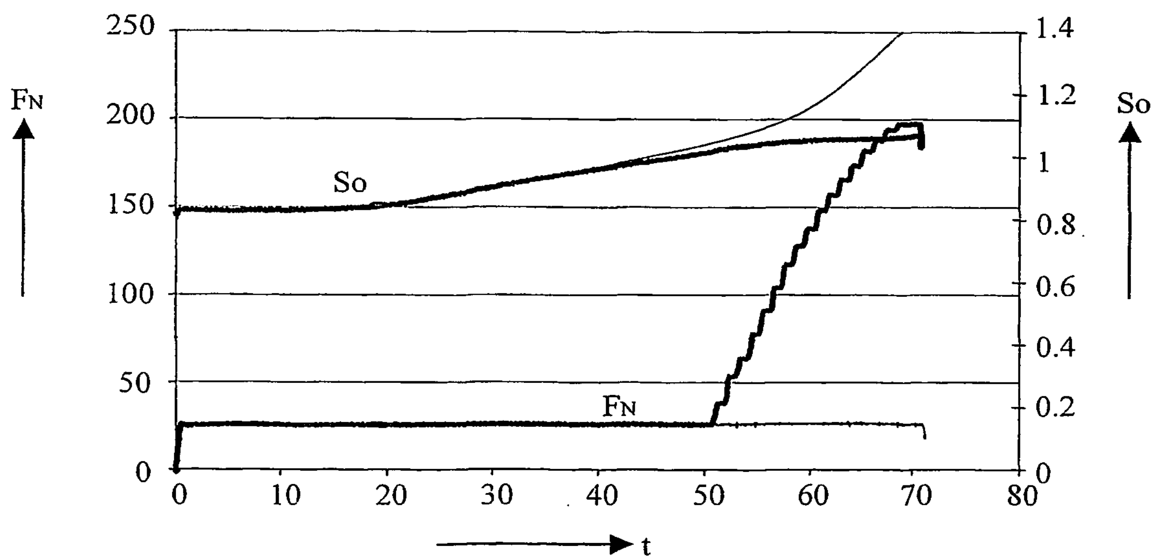
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Fig. 4

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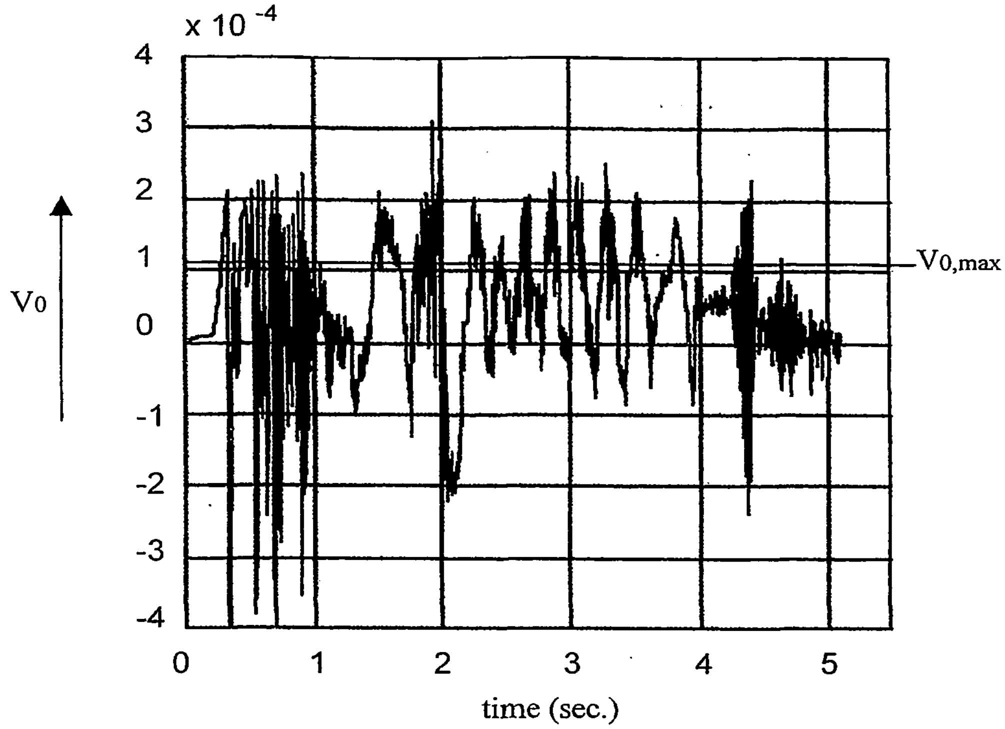
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Fig. 5A

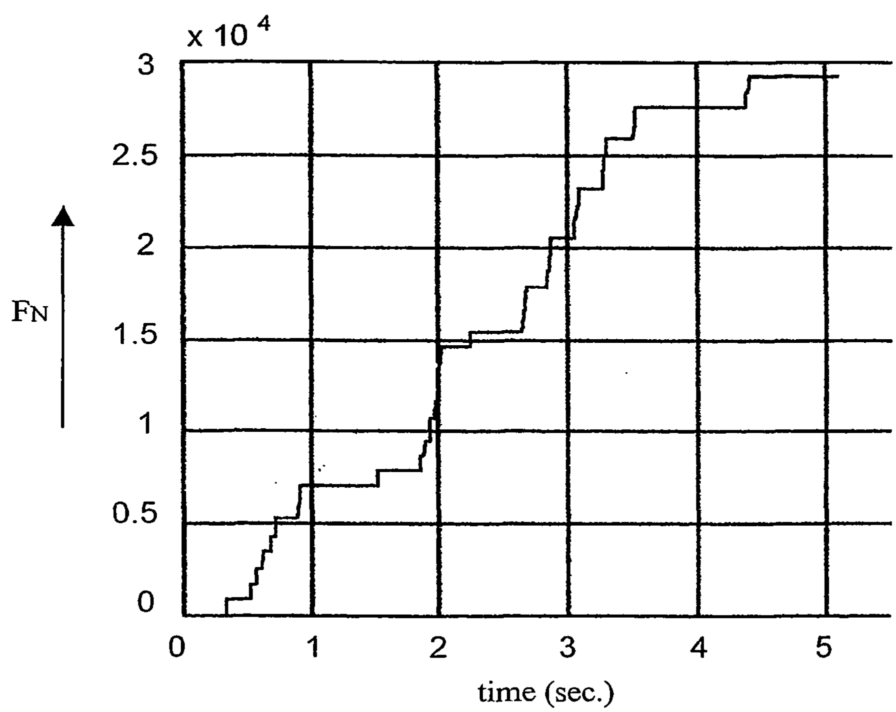
x 10 4
3
2.5
2
1.5
1
0.5
0
FN
0
1
2
3
4
5
time (sec.)

Fig. 5B

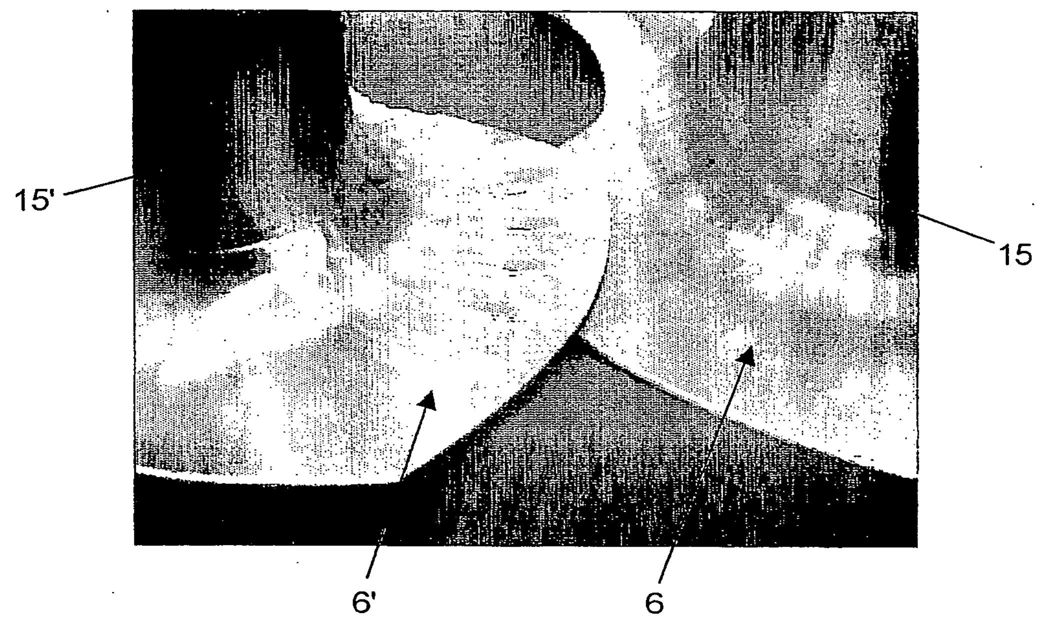

Fig. 6

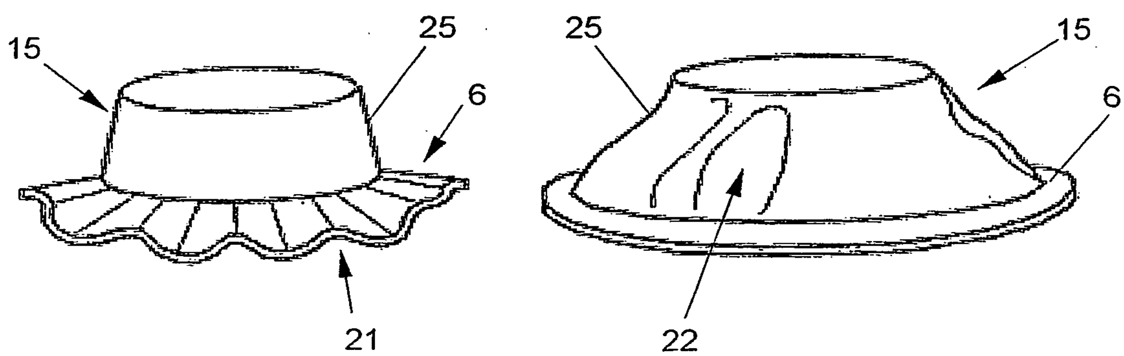

Fig. 7

INTERN^T^ONAL SEARCH REPORT

International :ation No
PCT/NL 03/00720

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 B21D24/14 B21D22/21

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 B21D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 40 38 864 A (FORSCHUNGSZENTRUM FUER UMFORM) 19 September 1991 (1991-09-19) cited in the application the whole document ---	1,8
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X	EP 0 703 018 A (MUELLER WEINGARTEN MASCHF) 27 March 1996 (1996-03-27) the whole document ---	8
X	EP 0 312 809 A (DAIMLER BENZ AG) 26 April 1989 (1989-04-26) the whole document --- -/--	8

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
29 January 2004	05/02/2004

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Peeters, L

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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